Towards a Digital Thread Between Industrial Internet of Things and Product Lifecycle Management: Experimental Work for Prototype Implementation

Piers Barrios, Benoit Eynard, Christophe Danjou

Towards a digital thread between industrial internet of things and product lifecycle management: experimental work for prototype implementation

Piers Barrios[1,2], Benoit Eynard[2], Christophe Danjou[3]

[1]Gfi Informatique, Meudon-la-Forêt, France
piers.barrios@gfi.fr
[2]Université de technologie de Compiègne, Compiègne, France
benoit.eynard@utc.fr
[3] Polytechnique Montréal, Montréal, Canada
christophe.danjou@polymtl.ca

Abstract. With the growing number of internet of things (IoT) and their miniaturisation, the technical possibilities associated with data collection are multiplied. In the future, it will be possible to install a sensor anywhere for a small cost. On the other hand, product lifecycle management (PLM) is a growing societal concern and products will need to be designed in such a way as to minimize their impact, while allowing businesses to have a viable business model. It will therefore be necessary to integrate data, coming from industrial internet of things (IIoT) into product lifecycle management, for companies to be able to offer product-as-a-service and pay-to-use. This paper aims to describe current advances on the integration of industrial internet of things in product lifecycle management. It also describes a prototype for a digital thread between IIoT and PLM allowing us to put forward open questions regarding the integration.

Keywords: PLM; IIoT; Digitalization; prototype; implementation

1 Introduction

The miniaturisation of computers allows everyone nowadays to have a handheld computer, whereas a few years ago it was a resource shared by multiple actors within a company. Everything suggests that tomorrow the miniaturisation of microelectronic systems (MEMS) will continue. These systems today have a lot of connected usage invading our day-to-day life: wireless headsets and earphones, badges of all kinds, mobile phones nec plus ultra, connected watches, speakers with voice assistants, etc. The list, of course, is not exhaustive as Internet of Things (IoT) continues to grow.

These modifications have not yet been entirely considered by companies as the difficulties and the challenges are huge: The Industrial Internet of Things (IIoT) should be dissociated from standard consumer IoT as the constraints are quite different. IIoT systems need more security, better reliability, a lower response time than consumer IoT and are, most of the time, to be added to existing assets rather than IoT which starts from scratch [1]. Moreover Russell [2] phrases the difference as follows: “While IoT in general focuses on distributed sensors and control systems, the main difference in Industrial Internet of Things uses similar concepts in mission-critical/industrial facilities.” This goes to further underline the duality of IoT and IIoT.

Among the difficulties related to IIoT projects, the technical limits and the diversity of applications along with the absence of a roadmap are the difficulties that are most likely to lead to a project failure. To improve the results, a global approach and methodology regarding IIoT and its integration in existing systems should be established.

On the other hand, Product Lifecycle Management (PLM) has been around for a few decades now and is defined as follows by Terzi [3]: “PLM can be broadly defined as a product centric – lifecycle-oriented business model, supported by ICT (information and communication technologies), in which product data are shared among actors, processes and organisations in the different phases of the product lifecycle for achieving desired performances and sustainability for the product and related services.” Therefore, PLM talks about the full lifecycle of a product whereas PLM as implemented in most of companies’ ICT systems often encompasses only certain phases of the lifecycle. Moreover, most of the time only Beginning Of Life (BOL) is taken into consideration by PLM. This dissociation appears more evidently as companies are starting to talk about Application Lifecycle Management (ALM) and Service Lifecycle Management (SLM).

Digital Thread is the ability to dispose of product information from and to any phase of the product lifecycle, hence avoiding data loss or corruption (i.e. from human copying) and enabling extended features to be developed.

It seems that only companies that are heavily liable for their products are considering the whole lifecycle (aircrafts, nuclear power plants, etc.). Only a few companies such as Michelin (for tyres) and Rolls-Royce (for aircraft motors) have, to this day, been able to switch from selling products to selling products-as-a-service. Forecasters tend to talk a lot about product-as-a-service and pay-to use. Therefore, companies are going to have to be able to manage their product from ‘cradle to grave’ and to do so, information coming from IIoT and IoT is going to have to interact with existing PLM information and knowledge. It is therefore crucial to think about integration of IIoT and PLM.

To address this, the current paper will describe the current state of integration between IIoT and PLM. In the third part, we shall present a prototype that is being implemented. Finally, the further improvements that need to be added and the underlying remaining questions shall be presented.

2 Current status of IIoT and PLM integration

To picture the current state of IIoT and PLM integration, we shall first present the current status of IIoT. Secondly, current integration of PLM and IIoT is detailed. Finally, the few papers mentioning the integration of IIoT and PLM are reviewed.

2.1 Current state of IIoT

IIoT's technology stack comprises sensors, communication protocols and gateways as well as platforms. Although the latter will interest us more than the others, it is important to have a broad view of the different aspects of the IIoT in order to grasp the diversity inherent to the domain.

Concerning sensors, the trend is toward battery-less sensors. Radio frequency identification (RFID) and Near Field Communication (NFC) allowed in the past decade to have extended item recognition as together they permitted the creation of passive tags that are remotely checked. Today, sensors are able to collect surrounding energy in order to function [4], to be activated remotely in order to get a measure [5] or even 3D-printed to send a precise signal [6]. Furthermore, improvements are made to sensors leading to a continued decrease in costs.

Protocols are legion and many lists exist. Salman [7] catalogues many of them across the multiple Open Systems Interconnection (OSI) layers and presents six IoT challenges: mobility, reliability, scalability, management, availability and interoperability. These challenges listed here were meant to be specific to communication protocols but could be generalized to any IIoT project.

Gateways are mostly hybrid components between sensors and platforms as they sometime serve as one or the other but can also be dissociated and be a communication relay or a computing on-edge device.

The main problem with "IoT platform" is the absence of a common definition. Therefore, lots of ICT based systems are identified as IoT platforms. Hoffman [8] identified 212 "IoT platforms" and proposed a long-list and a short-list of the platforms in the scope of "internet of production". However, if one wants to interact with IoT, it's most probably going to be through those kind of platforms, interoperability will therefore be key and multiple European projects are currently working on this aspect [9].

Finally, Liao [10] presents a systematic literature review on IIoT. It is interesting to notice that only 8 of the 94 articles retained talked about "practical solution" whereas the majority use "experimental solution" (72), the remainder being "review or survey" (6) and "theoretical solutions" (8). However, industry is currently looking for practical solutions therefore we shall try to work in that direction. In this sense, Anjomshoaa [11] proposed a practical solution, including analysis of feasible solutions, sensor choice and image analysis, but applied it to an adjacent field to IIoT: Smart Cities. Another sector alongside IIoT, where this work was found, is agriculture; Klein [12] proposes an IoT irrigation system allowing improved performances.

However, in these few fields, no PLM or industrial application was mentioned and no question was raised concerning integration of IoT with PLM. Similarly, no industry application was mentioned by Belapurkar [13] although a thorough analysis of smart space application was made for healthcare, public safety, environmental monitoring and commercial applications. Wang [14] presents "IoT for next-generation racket sports training" without mentioning management of the product itself via PLM for instance. However, next-generation racket sports trainings are necessarily going to need new rackets and product lifecycle management will be essential to do so.

In these numerous cases, IoT and the system as a whole would benefit from interactions with PLM. However, we found no explicit mention of this.

2.2 PLM and IIoT integration

PLM's integration in various systems has been studied in the past. Considering IIoT as being a new ICT system, looking at previous PLM integrations, the latter could give us clues towards its integration with IoT. In [15] ,Bosch-Mauchand et al. proposed an integration of PLM and value-chain simulation (among others) in order to better knowledge capture. However, knowledge is low volume and high-quality data on the contrary to IoT, which consists of high volume and low quality (when considered independently).

Concerning PLM and IIoT, little was found. In [16] Menon et al. proposed a critical analysis of some IoT platform performances based on their openness from the scope of PLM. Hence, they underlined the possible use of these IoT platforms during the different phases of a product lifecycle: beginning, middle and end (BOL-MOL-EOL). However, integration between PLM's ICT and these platforms at the various stages where opportunity wasn't discussed. In [17] Hehenberger et al. talk in one paragraph (3.4) about "Product lifecycle management for CPS": IoT being part of any Cyber-Physical System (CPS), the approach stays on a high level and does not mention integration of CPS' IoT into PLM. Nevertheless, separation of PLM approaches between hardware and software mentioned could be reused as IIoT and PLM integration is discussed.

In [18], Kadiri et al. mentioned the importance of IoT in context-aware infrastructures but no system integration is studied although a focus is made on Enterprise Resource Planning (ERP) systems.

However, there is a need for PLM systems to handle the increasing amounts of data being made available by IoT [19]. As the information available on explicit PLM and IIoT integration is scarce, we investigated possibilities of semantic interoperability through ontologies.

On the PLM side, in [20] Sriti et al. proposed an ontology for product information exchange. Still from a PLM point of view, Kiritsis [21] presented various technologies, some of which are IoT ones, in order to achieve a closed-loop PLM. However, IoT is not considered as an independent system and therefore its integration with PLM was not discussed. From a more global point of view, Kadiri et al offered in [18] a broad picture on ontology-based approaches and addresses ICT as a whole without entering into PLM and IIoT specifics.

However, ontology-based integration remains in question as its adoption in industry is scarce and we want our methodology to be adopted easily by the industry. Yoo [22] describes a conceptual framework but hasn't put forward a practical use-case. Also, considering adoption by industry and the return on investment for such a project, the case study developed by Alcatel Alenia Space in [23] showed how complicated it can be to evaluate Key Performance Indicators (KPI) in large scale projects such as PLM, as both process and working methods change at the same time. It would therefore be interesting to have such data available on IIoT and PLM integration.

3 A prototype of PLM and IIoT integration

Along with the deductive inferences that are made above, research will also be made by inductive reasoning, via the realisation of a prototype. We shall therefore present the prototype as it is currently, from both the architectural aspect as well as from the implementation point of view. We will also introduce the next architectural target for our prototype.

3.1 Current architecture & implementation

The current prototype consists of a PLM platform and an IoT platform connected to a 3D virtual environment to display information from both platforms. We shall detail the infrastructure itself, why we chose these options and how it has been helpful so far.

Currently, the aim is to display information in multiple devices thanks to UMI3D [24]. This information comes from a Windchill instance (from the PTC company) as a PLM solution, where the product's information is stored and a ThingWorx instance (also from PTC) as a IIoT solution, where the information relative to the sensors located on the product is stored. These instances have been successfully tested on a local Virtual Machine (VM), a company server as well as the provider's cloud, therefore allowing more flexibility depending on the use case. The Unity server then calls this information to display it in a virtual room that is accessed by multiple devices: personal computer, virtual reality headsets, tablets, etc. All this information is summarised in Figure 1.

Indeed, product's 3D model is the only data used at this point from PLM. However, being able to retrieve it is promising as it is the most difficult part. In future architecture, PLM metadata will be used to enhance product visualisation.

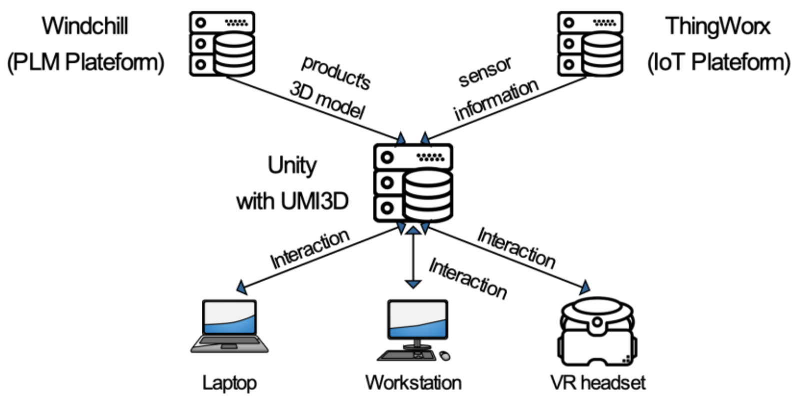

Fig. 1. Diagram of current prototype

The choice of a PLM platform was made towards Windchill as this was one of the two mastered by the team. This choice was made based on the openness of the solution, as integration of multiple solutions needs a minimum of interactivity. Concerning the choice of an IIoT platform, we are currently using ThingWorx, but are closely looking at other platforms as the multiplicity of solutions available reinforces the necessity to consider other options. Also, as underlined in [16], IoT platforms could be specific for use in for certain parts of the product lifecycle.

This prototype has been helpful in multiple ways: first, it allowed the team to understand the possibilities of interoperability on a technical level. As described previously, one could try to carry this interoperability to a higher level, even to semantic interoperability aiming to reduce adaptation cost, in case of a change of either the PLM or IoT platform. Second, we are facing questions on a practical level, which will no doubt help us to corroborate our comprehension of the theoretical ones. Finally, it moves us closer to having a complete integration of PLM and IIoT as discussed in the next section.

3.2 Target Architecture

In the long run and to investigate interactions between IIoT and PLM, we shall try to integrate closely both platforms. Therefore, we need to think a target architecture that would satisfy most needs.

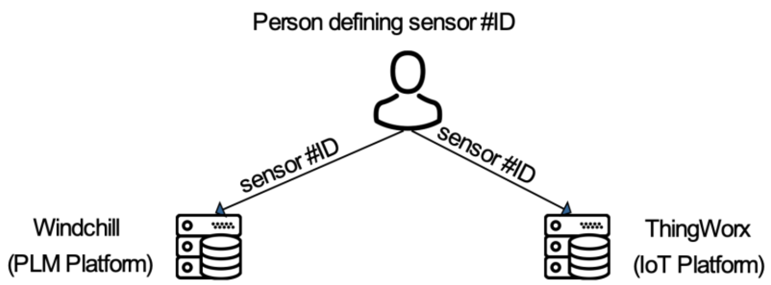

Fig. 2. Diagram of current issue with sensor ID attribution

The target architecture would consist of multiple tools and not only ICT and PLM, as some functions are not carried out by those tools. For instance, product instantiation is mostly managed in industry by ERP system or Manufacturing Execution System (MES). In the current architecture, someone must manually define the identification (ID) of the sensor in the PLM and IoT systems to be able to correctly pair information from both systems further down the road (into 3D visualisation in the current case)

(Figure 2). In the target architecture, product instantiation (and therefore sensor initiation) shall be supported via another ICT based system rather than the PLM or IIoT systems but shall make this information available for both systems (PLM & IIoT).

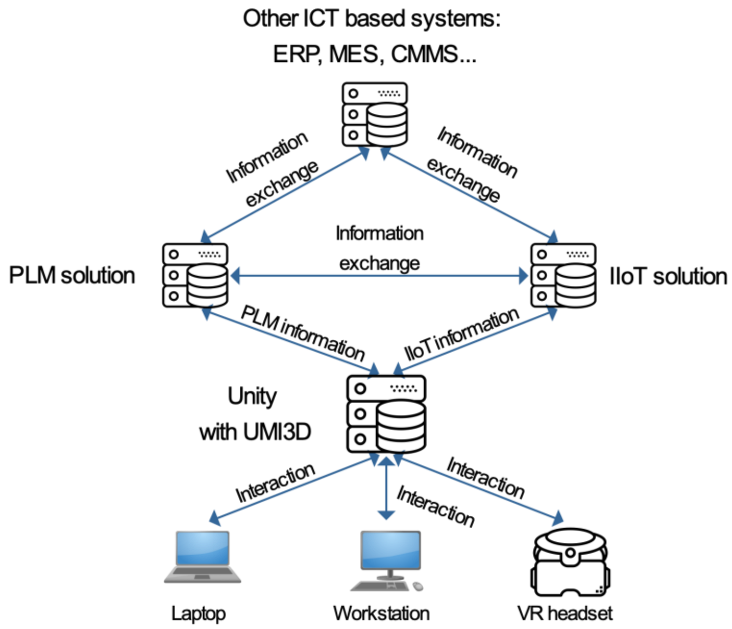

Fig. 3. Diagram of target architecture

In the same spirit, multiple information exchanges will need to be detailed in future works as each ICT based system holds information. We represented in Figure 3 the different interactions between inherent ICT based systems without detailing them, because much information and many orders can be given and received by those different systems. Although the current system offers the possibility to display information from multiple systems without having to do specific development for each device, in the future we would need to be able to send information back to the PLM and to the IoT solutions, based on the interactions made with the product, within the 3D environment. Also, information from both IoT and PLM systems should be available to the other systems for any actors to take any decision knowingly. The information should be delivered to the right person, in the right place and at the right time. With this in mind, we shall attempt to integrate the PLM and IIoT systems.

However, this will also depend on the use-case, as we will discuss in next section.

4 Further improvements and related questions

In this section, we shall present the different use-cases that our solution could match, as well as other further improvements that could be made. We will then discuss our implementation in the light of the current state of PLM and IIoT integration.

4.1 Improvements to approach real use-cases

Once the prototype is implemented, one naturally faces more practical questions coming from industrial stakeholders, such as “what is the aim of interaction between PLM and IIoT?” We shall try to present a few industrial use-cases and the necessary work in order to implement them into our prototype.

Firstly, the entry point consists of the usage feedback from the product prototype. In this case, the product is in a prototype stage and has only been produced either once or maybe a few copies. In this case, the aim is to visualise, in our 3D environment, the different measures made by the sensors to know which parts need changing and/or improving. Improvements needed to our prototype, in this use-case, would be to mark the parts in the 3D environment with a Problem Report (PR) or a Request For Change (RFC) which would be treated exclusively in the PLM environment. However, IoT information visualised at the time of issuing the PR/RFC would be needed inside the PLM to decide on the incumbent and create a Change Request (CR).

Secondly, the product is in a maintenance phase and historical data is needed on the product, both from a PLM and sensor point of view. Indeed, one needs to know the product history and what changes were made during previous maintaining phases, as well as usage data to know what happened in each phase. Moreover, any maintenance information carried out will need to be added to the PLM and then sensors could be calibrated at that point. In this case, our prototype should be able to display historical information from both PLM and IIoT systems.

Finally, products have been widely sold and this is a success; it is therefore time for a new version. Engineers are going to need agglomerated data on multiple instances of the product to visualise product information. Unfortunately, to this day, our prototype does not provide data integration in-between various phases of the product. The number of products instantiated, as well as the type and volume of information to display, would heavily impact the choice of implementation.

Here are listed only a few use-cases and these do not plan to be exhaustive, however, we went through the spectrum of numerous possible enhancements.

4.2 Discussion

As our experimental work for a full-fledged prototype implementation starts, we shall try to place it in the context of our readings.

First, the implementation of both platforms on a technical interoperability level is specific to each and every solution. Therefore, thinking of a semantic interoperability level could answer or at least diminish the integration complexity. Second, the prototype was nourished by the need to have a first-hand view on the different existing open questions. This has been very helpful to better understand the available literature.

The choice of IoT and PLM solutions were made based on the stakeholders' best knowledge. However, that turns out to give a certain bias on the solution and the questions we are facing. It would be pertinent to benchmark these choices against others. Unfortunately, no other PLM and IIoT implementation has been found by our team to this day. One of the reminding possibilities would be to carry this work. Moreover, the proposed target architecture will need further narrowing, as interaction between the different ICT based systems are studied more closely.

Last but not least, relying on industrial use-cases would allow us a more practical solution approach rather than staying on an experimental stage. However, we shall try to avoid the pitfall of a solution that is too specific and rather tend towards proposing a more global methodology.

5 Conclusion & Future work

In the ever-changing world we live in, the products' environmental impact could be diminished by improving various product-life stages using multiple sensors thanks to the Industrial Internet of Things. This would allow for more respectable methods of consumption and allow pay-to-use & product-service systems to develop further. However, PLM and IIoT systems have not yet been successfully integrated to achieve this.

For the purpose of creating a digital thread between IIoT and PLM, we have successively presented current state of IIoT as well as IIoT and PLM integration. We then explained the state of our current experimental work toward prototype implementation. Although not a full-fledged prototype, this allowed us to draft multiple open questions that shall be worked upon in further studies/articles, following the proposed target architecture. The possible use-cases were also drafted for such a system and finally discussed in the presented work.

Future work could consist of more thorough state-of-the-art experiments done through Systematic Literature Review (SLR). Moreover, the current prototype will be improved to lean towards the proposed architecture. During this process, integrations of both systems shall be discussed, as the information available and the process involved are quite thorough. Depicted use-cases could face some expertise from the industry to sharpen them and better answer the requests/demands. Finally, integration on a semantic level through ontologies will be investigated as an easier way to integrate PLM and IIoT systems.

6 Acknowledgement

Thanks to Julien Casarin, Cyriaque Dupoirieux, Christophe Theillaumas, François Loison, Dimitri Van-Wijk, Christophe Cazes & Laurent Clamens for working on the first version of the prototype.

7 Bibliography

1. Schneider, S.: The Industrial Internet of Things (IIoT): Applications and Taxonomy. In: Geng, H. (ed.) Internet of Things and Data Analytics Handbook. pp. 41–81. John Wiley & Sons, Inc., Hoboken, NJ, USA (2016)
2. Russell, L., Goubran, R., Kwamena, F., Knoefel, F.: Agile IoT for Critical Infrastructure Resilience: Cross-Modal Sensing As Part of a Situational Awareness Approach. IEEE Internet of Things Journal. 5, 4454–4465 (2018). doi:10.1109/JIOT.2018.2818113
3. Terzi, S., Bouras, A., Dutta, D., Garetti, M., Kiritsis, D.: Product lifecycle management - from its history to its new role. International Journal of Product Lifecycle Management. 4, 360 (2010). doi:10.1504/IJPLM.2010.036489
4. Ulukus, S., Yener, A., Erkip, E., Simeone, O., Zorzi, M., Grover, P., Huang, K.: Energy Harvesting Wireless Communications: A Review of Recent Advances. IEEE Journal on Selected Areas in Communications. 33, 360–381 (2015). doi:10.1109/JSAC.2015.2391531
5. Merenda, M., Felini, C., Della Corte, F.G.: Battery-less smart RFID tag with sensor capabilities. In: 2012 IEEE International Conference on RFID-Technologies and Applications (RFID-TA). pp. 160–164. IEEE, Nice, France (2012)
6. Iyer, V., Chan, J., Gollakota, S.: 3D printing wireless connected objects. ACM Transactions on Graphics. 36, 1–13 (2017). doi:10.1145/3130800.3130822
7. Salman, T., Jain, R.: Networking protocols and standards for internet of things. In: Geng, H. (ed.) Internet of Things and Data Analytics Handbook. pp. 215–238. John Wiley & Sons, Inc., Hoboken, NJ, USA (2016)
8. Hoffmann, J., Heimes, P., Senel, S.: IoT Platforms for the Internet of Production. IEEE Internet of Things Journal. 1–1 (2018). doi:10.1109/JIOT.2018.2875594
9. Advancing IoT platforms interoperability. River Publishers, Gistrup (2018)
10. Liao, Y., de Freitas Rocha Loures, E., Deschamps, F.: Industrial Internet of Things: A Systematic Literature Review and Insights. IEEE Internet of Things Journal. 5, 4515–4525 (2018). doi:10.1109/JIOT.2018.2834151
11. Anjomshoaa, A., Duarte, F., Rennings, D., Matarazzo, T.J., deSouza, P., Ratti, C.: City Scanner: Building and Scheduling a Mobile Sensing Platform for Smart City Services. IEEE Internet of Things Journal. 5, 4567–4579 (2018). doi:10.1109/JIOT.2018.2839058
12. Klein, L.J., Hamann, H.F., Hinds, N., Guha, S., Sanchez, L., Sams, B., Dokoozlian, N.: Closed Loop Controlled Precision Irrigation Sensor Network. IEEE Internet of Things Journal. 5, 4580–4588 (2018). doi:10.1109/JIOT.2018.2865527
13. Belapurkar, N., Harbour, J., Shelke, S., Aksanli, B.: Building Data-Aware and Energy-Efficient Smart Spaces. IEEE Internet of Things Journal. 5, 4526–4537 (2018). doi:10.1109/JIOT.2018.2834907
14. Wang, Y., Chen, M., Wang, X., Chan, R.H.M., Li, W.J.: IoT for Next-Generation Racket Sports Training. IEEE Internet of Things Journal. 5, 4558–4566 (2018). doi:10.1109/jiot.2018.2837347
15. Bosch-Mauchand, M., Belkadi, F., Bricogne, M., Eynard, B.: Knowledge-based assessment of manufacturing process performance: integration of product lifecycle management and value-chain simulation approaches. International Journal of Computer Integrated Manufacturing. 26, 453–473 (2013). doi:10.1080/0951192X.2012.731611
16. Menon, K., Kärkkäinen, H., Wuest, T., Gupta, J.P.: Industrial internet platforms: A

conceptual evaluation from a product lifecycle management perspective. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture. 095440541876065 (2018). doi:10.1177/0954405418760651

17. Hehenberger, P., Vogel-Heuser, B., Bradley, D., Eynard, B., Tomiyama, T., Achiche, S.: Design, modelling, simulation and integration of cyber physical systems: Methods and applications. Computers in Industry. 82, 273–289 (2016). doi:10.1016/j.compind.2016.05.006

18. El Kadiri, S., Grabot, B., Thoben, K.-D., Hribernik, K., Emmanouilidis, C., von Cieminski, G., Kiritsis, D.: Current trends on ICT technologies for enterprise information systems. Computers in Industry. 79, 14–33 (2016). doi:10.1016/j.compind.2015.06.008

19. Holligan, C., Hargaden, V., Papakostas, N.: Product lifecycle management and digital manufacturing technologies in the era of cloud computing. In: 2017 International Conference on Engineering, Technology and Innovation (ICE/ITMC). pp. 909–918. IEEE, Funchal (2017)

20. Sriti, M.F., Assouroko, I., Ducellier, G., Boutinaud, P., Eynard, B.: Ontology-based approach for product information exchange. International Journal of Product Lifecycle Management. 8, 1 (2015). doi:10.1504/IJPLM.2015.068011

21. Kiritsis, D.: Closed-loop PLM for intelligent products in the era of the Internet of things. Computer-Aided Design. 43, 479–501 (2011). doi:10.1016/j.cad.2010.03.002

22. Yoo, M.-J., Grozel, C., Kiritsis, D.: Closed-Loop Lifecycle Management of Service and Product in the Internet of Things: Semantic Framework for Knowledge Integration. Sensors. 16, 1053 (2016). doi:10.3390/s16071053

23. Alemanni, M., Alessia, G., Tornincasa, S., Vezzetti, E.: Key performance indicators for PLM benefits evaluation: The Alcatel Alenia Space case study. Computers in Industry. 59, 833–841 (2008). doi:10.1016/j.compind.2008.06.003

24. Casarin, J., Bechmann, D., Keller, M.: A unified model for interaction in 3D environment. In: Proceedings of the 23rd ACM Symposium on Virtual Reality Software and Technology - VRST '17. pp. 1–7. ACM Press, Gothenburg, Sweden (2017)